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BAYER LEVERKUSEN (GERMANY)

Department for Crop Protection

## On the biology and control of *Haplodiplosis equestris* Wagner

by

Hermann Heddergott, Münster (Westphalia)

### Introduction

In 1958, *Haplodiplosis equestris* Wagner surprisingly occurred in unusual abundance in the south-west part of the district of Steinfurt (Westphalia) and in the Unna-Soest-Lippstadt area. In some places, *H. equestris* caused severe yield losses on wheat and barley, and less serious damage on oats and rye. As this gall midge species had not hitherto occurred as a harmful pest in Westphalia, the infestation caused a great stir among farmers and in crop protection circles, with the result that it was decided to conduct the studies described in this paper. I am greatly indebted to Fräulein Friedel Esch, my co-worker for many years, for her untiring assistance in the investigations, and also to Herr Michel, senior extensionist of the Crop Protection Office at Münster, for first reporting the infestation and for his constant observations at the test sites.

The *Haplodiplosis* species observed in Westphalia is identical with the species discovered by Faber (1959) in East Tyrol. The assumption expressed in Faber's paper that the populations in North Germany might have developed from a special "flat country strain" had to be checked by studying comprehensive material from the different areas of infestation. The midges that occurred in the hilly regions of Sauerland could not be distinguished morphologically from those found in the flat country regions. Infestation in Sauerland, however, was restricted to heights of up to about 400 metres a. s. l., whereas in Tyrol *H. equestris* Wagner occurred at heights of between 1000 and 1300 metres (Faber, 1959).

### I. Spread of *H. equestris* Wagner

#### 1. Occurrence in Europe

Faber (1959) provides exhaustive information on the spread of *H. equestris* Wagner based on data in the pertinent literature, which reveals that the species occurs all over Europe. There is evidence of isolated specimens having been observed in North and North-West Germany, whereas mass occurrence is reported only from Westphalia (Heddergott, 1958) and Rhineland (Schick, 1958). In the meantime, isolated individuals of the species have also been identified at other places. Waede (1959) observed *H. equestris* Wagner in different parts of North Germany, and it has been known for some years to occur more abundantly in Holland.



## 2. Spread in Westphalia-Lippe

A systematic check carried out in 1959 in Westphalia and Lippe by extensionists of the Münster Crop Protection Office on *H. equestris* Wagn. infestation in grainfields provided reliable data on the spread of this pest in the area.



Fig. 1: Occurrence of *H. equestris* Wagn. in Westphalia-Lippe, 1959

Wheat and barley fields were primarily examined, experience having shown that these crops are chiefly attacked. Investigations were also made at the same time to establish crop rotation in the fields concerned during the last three

years, and to bring to light any information of evident damage, e. g. failure of plants to head, stooping of stalks and yield decreases.

Fig. 1 provides a picture of *H. equestris* Wagn. spread in Westphalia as established in 1959, making allowance for infestation density. The heights of the infested locations are given because these may have bearing on the final settlement of the question whether populations that occur in different areas are special ecological strains. It is evident from the map that infestation is mainly centred in the south-west of the Steinfurt district where the pest was first observed in 1958. From here, infestation spread primarily in the direction of south-west. A marked local increase of population density was also indicated in the Unna—Neheim-Hüsten—Soest—Lippstadt region where isolated *H. equestris* Wagn. larvae were found in all parts in 1958. However, outbreak of mass infestation was confined to narrowly limited areas; the reasons for this will be discussed later. In 1959 the population density underwent an appreciable, general increase in the same region but once again extreme multiplication took place only under certain conditions. The zone of rapidly increasing infestation, however, expanded southwards into Sauerland where isolated *H. equestris* Wagn. specimens occurred more abundantly especially on hill-slopes at heights of up to 300 — 400 metres. A local mass occurrence was observed in 1959 near Grevenbrück. Hitherto only isolated infestation had been encountered in the eastern districts of Westphalia.

The first increase in the population density of *H. equestris* Wagn. was definitely confined to areas with heavy soils, and it was also in these areas that infestation was mainly centred in 1958 and 1959. For instance, the Horstmar-Laer district is characterized by wet and partially heavy podzol loam or clay; the same type of soil is to be found in the west and south of Münster. The relationship between changes of the population density of *H. equestris* Wagn. and the nature of the soil is confirmed in that only very isolated occurrence was observed on the sandy soils between the northern and southern regions of main infestation. On the other hand, extreme mass infestation occurred on the heavy loam-clay soils in the Herzfeld-Lippborg district. The population density increased very distinctly in all places where "islands" of sandy or pure loam are located within regions of light sandy soils. For instance, the narrow stretch of loam soil from Waltrop to Herten north-east of Recklinghausen was heavily infested whereas the area of light sandy soils farther north was only slightly colonized by the pest. A general increase of population density was observed also in the areas of loess-like clay or loess-clay, along the Hellweg between Dortmund and Erwitte. Even in the southern centres of infestation at Günne, Herdringen and Grevenbrück, heavy loam soil — although often only to a very limited degree — is to be found at the places where mass reproduction took place.

The fact that heavy soils apparently offer *H. equestris* Wagn. very favourable conditions for development may be attributed to the requirement of the species for considerable moisture. On assessing data in the literature on severe occurrence of *H. equestris* Wagn., one is not far wrong in assuming that calamitous outbreaks of infestation especially take place after long periods of persistent rainfall such as recorded in North-West Germany from 1956 to 1958. Rainy years have their effect particularly on heavy soils because these retain water for extremely long periods. The fact that *H. equestris* Wagn. is a relativ-



ely hygrophilous species is confirmed by its relatively high population density in England and the increasing multiplication in Holland.

Apart from the influence of the soil, crop rotation also has special bearing on changes of population density in cultivated areas. The Horstmar-Laer region is a main centre of cereal-growing. The usual crop rotation here includes intensive cultivation of wheat, rye, barley and oats, often with no change in the rotation. This provides *H. equestris* Wagn. with very favourable conditions for its mass development not only in a few fields but also over a large area. For this reason, the population density in this region was uniformly very high in all grainfields, and infestation constantly spread with clearly recognisable gradients from certain sources in the south-west of Burgsteinfurt.

In contrast, infestation in 1958, although widespread, was moderate in the Hellweg region (Soester Börde), where crop rotation changes regularly from cereals to root crops, despite a very high percentage of grain cultivation and favourable soil conditions that year; in fact there were no large centres of infestation from which the pest might have spread. Extreme mass occurrence was always restricted to isolated fields. Precise investigations proved in every case that at these places cereals had followed cereals several times in the crop rotation or that cereals had been grown after grass seeding. Grainfields situated in the immediate vicinity of severely infested fields were only moderately colonized.

The situation was the same in 1959. *H. equestris* Wagn. once again was generally widespread in the Soester Börde region, and the population density had also appreciably increased as compared with 1958, but local mass multiplication was once more restricted to only a few cases. In places where root crops were cultivated as the following crop in fields that had been severely infested in 1958, only relatively slight infestation of peripheral plants took place even in the immediate vicinity of soils severely infested with larvae.

## II. Morphology

### 1. Imago

#### a) Head

The clearly offset, orthognathous, oval head is relatively small, with only few bristles. The lateral sections are almost completely taken up with the large, black compound eyes which contain numerous, clearly defined ommatidia, and joined at the vertex by a narrow sclerite that also bears several ommatidia at the edge. The slightly projected clypeus is offset from the lighter, soft skinned, movable labrum by its more pronounced chitinization. The maxillae, except for chitin spicules, are reduced with clear tactile receptors. Their last segment is at least a third longer than the second in the male, and hardly any longer in the female. The basal parts of the labium are firmly coalesced appearing as one unit; only the terminal segments of the reduced palpi remain free in the form of wide lobes.

The freely mobile scapi of the antennae, articulated with large palp pits, are short and compact; the pedicelli, on the other hand, are spherically distended. In both sexes, they bear a palp flagellum consisting of 12 segments. The first segment is formed by the fusion of 2 normal segments, already referred

to by Rübsaamen (1926). The former division of these segments is recognized from the interruption of the fine bristle covering at this point just as on the other antenna segments. The differences between male and female palpi are described in greater detail by Faber (1959).

## b) Thorax

The large, oval occipital foramen is situated well towards the vertex. The relatively long, wrinkled, soft-skinned "neck" or cervicum is supported by two long and narrow, lateral cervical sclerites; one articulates with the postoccipital condyles of the head, and the other with the propleura on the pro-thorax, guaranteeing ready mobility of the head.

The greatly reduced pro-thorax forms only a narrow supporting ring for the first pair of legs, this being a typical feature in *Nematocera*. The mesothorax, on the other hand, as the bearer of the wing muscles, is very well developed. Dorsally it bears the well-projected scutellum to which the powerful, dorsoventral muscles are attached. The mesophragma, for the insertion of the dorsal, longitudinal muscle fibres, is a strongly chitinized projection, and protrudes through the first abdominal segment almost as far as the second one. Compared with the mesothorax which bears the wings and the second pair of

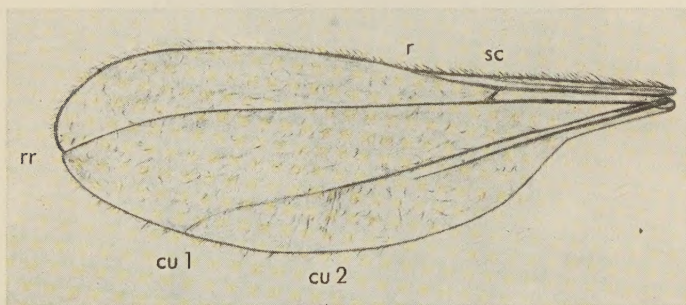


Fig. 2: Wing of *H. equestris* Wagn.

legs, and takes up the greater part of the length of the thorax, the narrow metathorax is greatly reduced. The metathorax bears the halteres and the third pair of legs. The pro-thoracic stigma is indistinct, being situated about level with the neck attachment. The mesothoracic stigma, on the other hand, is easily perceptible below the wing base.

The wings are narrow as they emerge from their radicular zone, but then considerably expand. The surface of the wings, like the stipes of the halteres, is covered with a dense layer of fine hairs, and at the front edge there is a row of strong bristles. Compared with the description of the wings by Faber (1959), the material collected in Westphalia shows the following differences:  $CU_1$  is distinct only about as far as the point at which  $CU_2$  branches off;  $CU_2$  is present only in rudimentary form, and on some specimens it is hardly or not at all visible. Otherwise, the development of  $CU_1$  and  $CU_2$  corresponds to



Faber's description, likewise the transverse vein between r and rr. Special mention should be made of the marked indentation of the wing periphery at the point of anastomosis at rr (Fig. 2).

The third pair of legs are long and sturdy, with a dense covering of blackish bristles. Their construction is typical. Coxa and trochanter are somewhat rectangular, and femur and tibia are very elongated. The tarsus, the second segment of which is the longest, bears a short pretarsus on the 5th (last) segment together with two simple, well-curved claws tapering into a sharp point. These claws arise from a common basal section which in comparison with the very dark colour of the claws, appears to be more membranous but it is so heavily chitinized that it can articulate flexibly with the dark, irregularly dentated unguifer of the last tarsal segment. The longitudinal, lobate empodium always protrudes somewhat beyond the claw curvature in the examined Westphalian specimen of *H. equestris* Wagn., so that it is about as long as the claw.

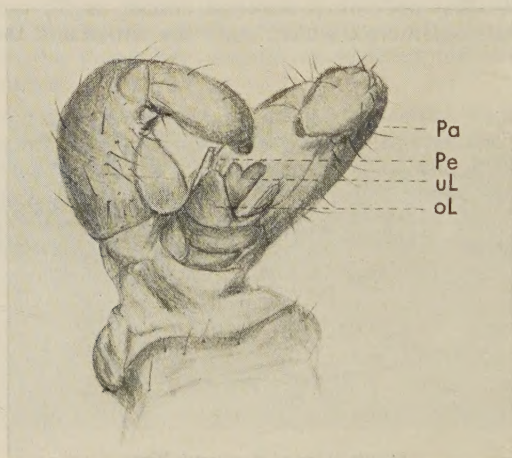


Fig. 3: Copulation organs of male, viewed dorsally from any angle:

Pa = parameres, Pe = penis, uL = middle, lower lamella, oL = "lateral", upper lamella

### c) Abdomen

The abdomen of the male consists of 7 rather similar segments, an eighth which is much smaller and somewhat flattened dorsoventrally, and the adjoining external genitalia which comprise parts of the ninth segment and the actual copulation appendages. The latter include, viewed from the dorsal to the ventral side, the lateral "lamellae" protruding on both sides as tips of the dorsal, arched terminal of the copulation system, below these the "middle lamella" which protrudes well out, is clearly perceptible but not very deeply indented, and below this again the azygous penis (Fig. 3).



The penis and "lamellae" are consolidated and laterally enclosed by the large, paired, tong-shaped, bipartite parameres. Their basal segment is wide and oval. The articulation surfaces form a ventral termination of the copulation system. The second segment is tong-shaped, and curved inwards and upwards so that in a position of rest the heavily chitinized tips almost touch.

The abdomen of the female comprises 7 normally developed segments bearing clearly perceptible tergites and sternites, and also the 8th, 9th and 10th segments modified in relation with the development of the ovipositor or egg-laying organ. The 8th segment is considerably modified, appearing to be tubular without any perceptible separation of tergite from sternite. The main component of the adjoining 9th segment is the relatively short ovipositor which is inserted in the 8th segment, but is not so mobile as in forms with an extremely protractile ovipositor. Corresponding to this, the ovipositor of *H. equestris* Wagn. is retractile and protractile for only about two-thirds of its outer length, which is not much beyond the mobility of the other body segments.



Fig. 4: Female *H. equestris* Wagn.

The female abdomen terminates dorsally in two oval, valve-like, adjacently arranged "upper" lamellae. Below these, yet above the outlet of the ovipositor, is a small appendage usually described in the literature as the "lower" lamella which, in conjunction with a more ventrally situated, heavily chitinized, obtuse basilar process and the upper lamellae, has the function of ensuring, during oviposition, that the egg is carefully guided out and firmly pressed against the surface on which it is laid.

The two sexes differ not only in the dissimilar development of the tactile organs and terminal abdominal segments but also most distinctly in their size,

body shape and colour, this being evident merely from a superficial observation. Therefore, a detailed description of the male will now be given first.

Length of the male body, less feelers, 3.6 to 3.9 mm, span of the wings 8 to 9 mm. Basal segments of tactile receptors brownish-grey, flagellum light yellowish-brown, long bristles, mouth-parts brownish-grey.

Cervicum brownish-yellow, cervicalia dark-brown. Thorax, dorsal, glossy dark-brown to blackish, in raised median section especially dark, being lighter in parts with yellowish-brown stripes giving the impression of a light line formation, these lines becoming denser towards the posterior to form a yellowish sector. Scutellum lead-grey to greyish-black. Lateral sclerites of the thorax blackish-brown, cutaneous parts being lighter in colour, in fact more yellowish. Wing surface mat-grey except for yellowish base, slightly iridescent in the sun, front edge tinted yellowish-brown, venation yellowish-brown, stipes and radicles of halteres lightish yellow, there usually being fewer than in the

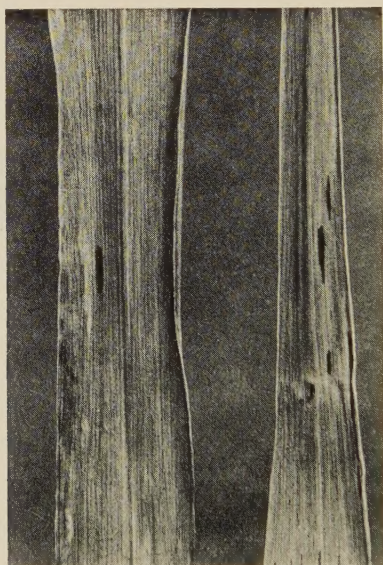


Fig. 5: Egg pods of *H. equestris* Wagn. on barley leaves

female, shoulder brownish-yellow, with a reddish tinge in contrast to the radicle. Legs yellowish-grey to yellowish-brown.

Abdomen of fine granular structure, primary colour dull yellowish-brown, tergites dark-brown being somewhat lighter in colour in the middle, so that dorsally a light unbroken pattern is formed, and a dark pattern at the segmental divisions. Pleura matt yellow-brown, sternites dark-brown. Genital appendages yellow-brown inside, dark outside, the final paramere segment being dark-brown. The basal plate is amber-yellow.



The male has the general appearance of being slimmer and darker than the female for the matt, yellowish-brown (not red!) primary colour of the abdomen is covered, to a greater or lesser degree, by the dark tergites. The thorax and abdomen of both sexes are abundantly covered with bristles some of which are quite long.

Length of female body 4.2 to 4.4 mm. Span of wings 7.5 to 9 mm. Scutellum yellowish-grey, lighter than in male. Radicular zone of wings more yellowish than in male. Radicles and stipes of halteres are yellowish, shoulder yellowish to yellowish-red. Abdomen is primarily flesh-coloured (cherry-red). Tergites and sternites are of a darker brownish-red. Ovipositor yellowish, upper lamellae dark-brown. Older individuals appear to be generally somewhat darker.

## 2. Egg

The egg is elongated and oval. When laid singly, it has almost parallel sides and short, rounded poles. Usually, however, the eggs are laid in rows so that they touch each other and are, therefore, sometimes flattened at the poles, especially as the female presses them firmly against the surface on which they are laid. The chorion is thin and flexible with a smooth and structureless surface, appearing glossy from the top view.

Freshly laid eggs have an intensive rust-red colour, changing to a light rusty brown after a few hours. Egg pods which are 2 to 3 days old appear dark brown. The eggs of some pods have dark chocolate-coloured spots on a glossy, light-brown primary tone. But after a few hours, these eggs also change to a uniform dark-brown colour. Embryonic development lasts 6 to 7 days at a temperature of 18 °C.

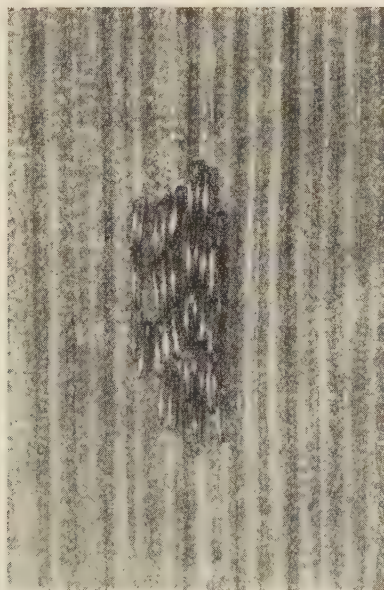


Fig. 6: Egg pod, magnification  $\times 12$

Differentiation begins 10–12 hours after the egg is laid. During its process, the centre of the egg takes on a lighter yellowish-brown colour after 3 days, until finally two dark-brown pole caps clearly form (Fig. 6). As the process of development continues, only the animal pole remains dark, and the other one becomes lighter until finally its colour is more like the now milky, light egg centre. At about 18°C, the form of the embryo becomes vaguely apparent from the 4th day, and gradually its body outline becomes clearer. The divisions of the segments are clearly perceptible from the 5th day. After the larva has emerged, the tender chorion remains for a time on the leaf as a fine, slightly iridescent shell, but as a rule it soon falls off the leaf.

The differences in the size of the individual eggs are most considerable. On barley, the smallest egg measured  $0.45 \times 0.06$  mm, and the largest  $0.52 \times 0.08$  mm. Twenty measurements produced an average size of  $0.49 \times 0.07$  mm.

### 3. Larvae

The freshly hatched larva measures on the average 0.45 mm long and 0.05 mm wide. In colour and shape, it at first shows no change from the about-to-hatch embryo of the final egg stage. Dorsoventrally, the body is flattened and is glassy and transparent, although in its general outlook it appears pale brown due to the intensive colouring of the internal organs. The intestinal tract with its appendicular glands is a dark reddish-brown for its colour is largely determined by the yolk still present in it. The stigmata and their tracheal extensions are clearly visible, and also the longitudinal tracheal trunks glitter through the body skin. The lateral fat-body arrangement appears lumpy, and has a more whitish colour. Although segmentation in the young larva is perceptible, it is not so marked as in the later instars.

During its movement towards the ligule and between the sheath and the haulm, the insect takes in no food, living at first from the yolk reserve in the intestine. The general resorption of its food reserve can be clearly followed for during this period the larva has a more brownish, spotted colour. The final, coherent yolk complex is found in the mid-intestine. After this has been consumed, the larva has a glassy, colourless appearance which it retains even after the first uptake of food. It is not until in the course of later development that its body becomes milky white and nontransparent.

The subsequent stages are very difficult to separate for it is only by accident that one once succeeds in observing the ecdyses of the insects while they are living under the sheath. It would seem that apart from the embryo, there are three other stages of larval development. The second stage would include larvae with a body length ranging from 1 to 1.8 mm, and which have a milky white colour, but becoming more yellowish just before moulting. A third larval stage, 1.8 to 2.8 mm long, is reddish-orange or reddish at both ends of the body, with the middle part of the body remaining white. The fourth and final instar is a 3 to 5 mm long, and 0.9 to 1.1 mm broad larva with an intensive red colour; its alimentary canal, filled with chyme, glimmers through the dorsum as a dark, longitudinal streak. The body surface has a rough granular texture, and a matt gloss. The position and shape of the thoracic spinae, distribution and hair covering of the papillae and expansion of the spine fields in the larvae collected in Westphalia correspond with the detailed description of Faber (1959) for the Tyrolean specimens. The position of the stigmata is also the same as in Faber's description.



#### 4. Pupa

In fresh pupae, the head and thorax are of a light yellowish colour, and the abdomen is light yellow. Later, the head and thorax change to a yellowish red-brown, and the abdomen to a dull red colour. Shortly before the imago emerges, the head, thorax and wing borders are slate-grey to black-grey, but the abdomen remains red. The head of the pupa bears two fine, light-coloured vertex bristles, and the thorax two strong respiratory horns, these being typical characteristics of the species. The abdomen is covered with fine spines, and the tergites bear fine and coarse spinous portions.

The differences in size are also considerable among individual pupae. In our measurements, the maximum length for the male was found to be 3.8 mm, for the female 4.5 mm, the minimum length for the male 3.2 mm, and for the female 4 mm. The average length calculated for 20 pupae was 3.6 mm for the male, and 4.2 mm for the female. The maximum width (thorax centre) measured was 1 mm for the male, and 1.3 mm for the female. Illustration of pupa in paper of Faber (1959).

The exuvia has a dark-coloured head section; the thorax and its appendages are light yellowish. The free receptor appendages protrude in the form of an arch. The transparent, milky white abdomen is parchment-like, and only the intersegmental skins have a slight dorsal pigmentation in the form of brown striae.

### III. Mode of life

#### 1. Imago

The imagines begin to emerge as soon as the top layer of soil has reached a temperature of about 18° C; in 1959, this was in early May in Westphalia. In laboratory breeds, the males regularly appear 1 or 2 days earlier than the females, and also in the field they make up the greater percentage of the initial population although in favourable weather conditions the first emergence period is condensed into so few days that both sexes appear practically at the same time.

*H. equestris* Wagn. is such a fragile species that strong winds will carry it over considerable distances although in active flight the insect is only capable of covering short distances. The rather inactive females, in particular, usually remain in the immediate vicinity of the place where they emerge, and settle on leaves, ears and stalks of cereal plants especially during the morning and evening, and in dull weather the whole day (Fig. 4). The midges have a very short life, especially the males. In dry weather, they die after only 2 to 3 days. We succeeded in keeping females alive for up to 7 days. Once the temperatures had become warmer, emergence in 1959 took place on a huge scale during the first two weeks of the flight period so that in some places there were mass accumulations not only of live midges but also of dead *H. equestris* Wagn. which often drifted together into large heaps in the angles of the leaves.

#### a) Oviposition

Copulation takes place, as Faber (1959) also mentions, immediately after emergence, usually in the soil zone still moistened with dew. As a rule, egg-laying starts immediately afterwards, and may be observed to continue the whole day, but especially in the morning and evening. In May, 1959 the midges

were to be seen laying eggs during the morning also when the sky was cloudless and the sun was continually shining. It was not until the temperature became hot at mid-day that they retired into the shady parts in the grainfields where they did not, however, lay many eggs.

Before starting to lay its eggs, the female midge first seeks a suitable place on the upper or lower surface of a leaf. It may be observed moving backwards and forwards along the leaf blade feeling the surface with the tip of the abdomen. When it finds a suitable point, it applies its ovipositor to the surface, and now follows a typical, short, yet very clear reverse motion, with the posterior curving in the form of a hook. This brings the tip of the abdomen into such a position as to guarantee a secure passage of the egg through the lamellae referred to earlier, whereby the egg will be firmly pressed against the leaf surface. The midge now remains still for an instant, then again moving slowly forward deposits one egg after the other rather quickly, usually in the groove between two leaf veins. In this way lengthy rows of eggs are deposited at a relatively fast rate; these rows assume a length of up to 10 mm in half a minute, corresponding to 15—20 eggs. The eggs lie on the leaf with their longitudinal side upwards and are only loosely stuck to the surface; in fact it is only necessary to bend the stalk for an egg pod to be removed without harming it. The chains of eggs are of varying length, and lie parallel to the leaf veins (Fig. 5). Up to 21 eggs have been counted in a single row. Often up to 8 rows may be observed so close to each other that they appear as one single array (Fig. 6). The egg rows are usually straight, and are seldom slightly superimposed. Isolated egg pods are to be found also on haulms and ears. The maximum number of eggs counted in one pod was 47. The maximum total of eggs laid by one female in the insectarium was recorded at 119.

## 2. Egg

In 1959, the leaves of the wheat, barley, rye and oat plants were heavily colonized with egg pods in the Laer-Horstmar infestation zone; a casual study sufficed to show that a high percentage of the eggs had a pale colour and were more or less severely deformed. Damage to the eggs ranged from slight shrinkage to complete withering. There is little doubt that this relatively high mortality rate of about 20 % was caused in 1959 by the extremely dry conditions in spring and summer, especially as embryonic development had progressed normally in the initial stages in many of the damaged eggs. Thus, the degree to which a cereal plant is colonized with eggs (Fig. 7) provides only a limited prognosis of the abundance of larvae that can be later expected. Unfertilized eggs are also frequently found.

## 3. Larva

The majority of the eggs are freely deposited on the upper or lower surface of the leaves and not at the leaf base, so that in order to reach the space between the stalk and sheath, the young larvae must crawl in a sliding motion down the leaf. They move as far as the next ligule, an operation that takes at least a few hours and often a whole day. The larvae are prevented from falling off the leaves by their prehensile organs on the flat underside of the body, assisted also by glandular secretion. The ability of the insects to cling firmly to a surface is demonstrated when young larvae are placed on a glass plate. They do not fall off the plate even when it is held upright, and can only be removed by overcoming a certain degree of resistance.





sheath narrows pressing firmly against the stalk, preventing a continued downward movement of the larvae. As more and more larvae constantly follow in the event of mass infestation, they gather at this point in large congested batches. On removing the sheath, the larvae are seen to appear as a brown layer on the stalk.

The young larvae of one egg pod usually migrate together down a stalk, crawling in file. Therefore, single young larvae are relatively seldom found moving downwards in the upper parts of the internodes. When, in the event of mass occurrence, further development of all larvae gathered in the node zone is not possible due to lack of space, the young larvae then spread out over the lower half of the internodes, as the stalk examinations, discussed later, clearly revealed. Older larvae, especially medium-sized stages, are therefore usually to be found farther above the node region.



Fig. 8: Larvae of *H. equestris* Wagn.

Movements of the young larvae on and under the leaf surface are controlled by their marked, positive geotaxis and thigmotaxis. When an egg pod is allowed to hatch on a slide, all the young larvae will soon gather closely together on the underside. Also in nature the insects continue to crawl downwards until they have achieved dorsal and ventral contact with a surface. Their efforts to force themselves into an opening are all the more intensive the narrower the opening.

Larvae that have already entered the sheath are difficult to observe. They are considerably disturbed on cutting open and removing the sheath (Fig. 8). Studies of exposed larvae attach only a limited value because the position

between the sheath and stalk constitutes an indispensable condition for natural behaviour. In fact such studies do not completely clarify conditions of locomotion although they do permit certain conclusions to be drawn. They clearly show that intensive motion lessens as the larva grows in size.

Following mass occurrence, small to medium-sized, whitish larvae are found clinging together so firmly in groups on opening the sheath that they are difficult to separate. The dense knot-like groups in which the larvae actively move and curl around each other, immediately fall apart when immersed in alcohol. Large larvae are less active. Secretion and clinging processes are also of certain influence among large larvae, this being proved by the fact that even these larger stages are often to be found grouped in knots both under the stalk sheath and when they leave it.

The crawling ability of the larvae especially enables them to move between the stalk and sheath. Larvae which were placed in a thin layer of soil spread over moist absorbent paper in open Petri dishes, crawled about continually as soon as the material became too dry. Large exposed larvae sometimes curl the ends of their body together in attempts to move about, half turning about their longitudinal axis in the process. After a time, they swing the ends of their body round to the other side so that they roll in the opposite direction. These rapid and rotary motions alternate relatively fast but they are not coordinated. Undoubtedly the biological purpose of these movements is that the forward motion of the larvae crawling in the soil is made easier between the soil particles, whereby the adjoining surfaces provide a support for the spinous zones.

The larvae become fully grown after 3 to 4 weeks, usually in June to July, when they leave the infested cereal plants as the stalks become yellow. After the sheath has started to wither, they force their way out between the sheath and the stalk. As long as the sheath still has a fresh green colour and lies firmly against the stalk, the larvae make no attempt to migrate. Larvae that have hatched out of eggs laid late in the season, are often not fully grown when the grain is cut, and are, therefore, to be found in large numbers in the threshing trash especially when combined harvesters are used. In 1959, this trash was so full of larvae in certain parts of Westphalia that the predominant red colour of the larvae in the trash caused a considerable stir.

The larvae leaving the stalk sometimes stick together in solid knots, also falling in one batch to the ground. They then separate to crawl into the soil. A check carried out on August 8, 1959 showed the larvae to be concealed in the soil at a depth of about 5 to 6 centimetres, and especially abundant in the root zone of the cereal stubble. The depth to which the larvae finally penetrate depends upon the firmness of the soil, usually being 8 to 10 centimetres although sometimes as much as 12 centimetres. The larvae continue to be very mobile also during winter dormancy so that they are able to change their position in the soil if forced to by extreme temperatures, moisture or other unfavourable conditions. This ability is of advantage, for example, to such larvae that have penetrated deep into the ground due to soil cultivation work after the grain harvest. In test diggings during the winter, larvae were found that had been ploughed under to a depth of 25 centimetres although they were no longer so deep down by spring. Assumedly they had actively migrated back to higher soil layers.

In winter, the larvae, with their ventral side curved out slightly, lie in a small hollow in the ground, which is lined with a few, very fine threads. Even

when it is carefully washed out of the soil, one seldom succeeds in isolating the web undamaged. Hollows that are not lined with a web (Faber, 1959) are undoubtedly made by larvae which have changed their original position in the soil. When disturbed, the larvae immediately begin to move with vigorous actions. Their reaction to agitation is very pronounced. Larvae that overwinter in an insectarium are observed to start moving at once as soon as the cover is lifted off the breeding vessel. When taken out of the soil, larvae very quickly begin to tunnel their way back again.

Faber (1959) reports that larvae of *H. equestris* Wagn. are capable of remaining in the same instar, not fully grown, for at least a year. In the Tyrol, it is estimated that such larvae make up about 10 % of the total population in the soil. In 1959, counts in Westphalia showed this percentage to be higher, in the region of 20 %. It is most remarkable that numerous small larvae were found still alive in the soil even in spring. In a soil sample measuring 10 × 10 cm down to a depth of 12 cm, taken on April 19, 1959, 214 larvae (and pupae) were counted, and included 19.5 % which were only 2 to 3 mm long and not yet fully red. The percentage of bigger larvae, 3—5 mm long, with a full red colour, was 74.6 %, plus 5.9 % pupae.

The ability of larvae that are not full-grown to overwinter in the soil and survive, may be attributed to their amazing resistance to external influences. When green cereal stalks containing half-grown larvae are cut off and allowed to dry, the larvae will still be alive after 4 to 5 months. It is, however, doubtful whether larvae that have not completed their growth in the stalk, can develop into adults.

When the warm season begins (in 1959, this was in mid-April in Westphalia), the larvae leave the deep soil layers and migrate close to the surface. In 1959, larvae were observed moving upwards until mid-June, and pupae until late June. Shortly before they pupate, the larvae often lie exposed on the topsoil. They again make a small hollow in the ground, which they line with a web spun from a few, very fine threads, and pupate in it.

#### 4. Pupa

Pupal quiescence lasts for 6 to 8 days at 18° C. Shortly before the imago emerges, the pupa pushes itself to the soil surface by lateral movements of the abdomen. In this motion, the spinous zones act as a support. The exuviae half protrude out of the ground, and only the abdominal zone remains anchored in the soil.

### IV. Host plants

#### 1. Infested plant species

*H. equestris* Wagn. originally occurred on wild grasses. In checks carried out in the course of these studies, larvae were discovered also on grass species growing on balks and slopes. *Phleum pratense* L. was severely infested, with larvae colonizing the stalks as far as the 5th internode. An unusually large number of larvae was observed. They were less abundant on *Agropyrum repens* P. B., *Dactylis glomerata* L., *Festuca elatior* L. and *Poa pratensis* L. Infestation on *Alopecurus myosuroides* Huds. was isolated, with only few larvae on the stalks.



Table 1: Number and distribution of different larval stages in 100 stalks, observed in a mixed crop of winter rye and winter barley; count on June 18, 1959

| Cereal        | Infested stalk section | Number of <i>H. equestris</i> Wagn. larvae in 100 stalks |        |       |                     |        |       |                   |        |       |
|---------------|------------------------|----------------------------------------------------------|--------|-------|---------------------|--------|-------|-------------------|--------|-------|
|               |                        | Youngest larval stage                                    |        |       | Medium-sized larvae |        |       | Full-grown larvae |        |       |
|               |                        | 1-10                                                     | 11-100 | > 100 | 1-10                | 11-100 | > 100 | 1-10              | 11-100 | > 100 |
| Winter barley | 1st internode          | 28                                                       | 56     | 10    | 14                  | 16     | 6     | 10                | 6      | 0     |
|               | 2nd internode          | 29                                                       | 28     | 1     | 7                   | 7      | 2     | 10                | 1      | 0     |
|               | 3rd internode          | 22                                                       | 5      | 0     | 1                   | 2      | 0     | 3                 | 0      | 0     |
| Winter rye    | 1st internode          | 27                                                       | 7      | 0     | 0                   | 2      | 0     | 0                 | 0      | 0     |
|               | 2nd internode          | 20                                                       | 4      | 0     | 1                   | 3      | 0     | 1                 | 0      | 0     |
|               | 3rd internode          | 6                                                        | 0      | 0     | 0                   | 0      | 0     | 0                 | 0      | 0     |

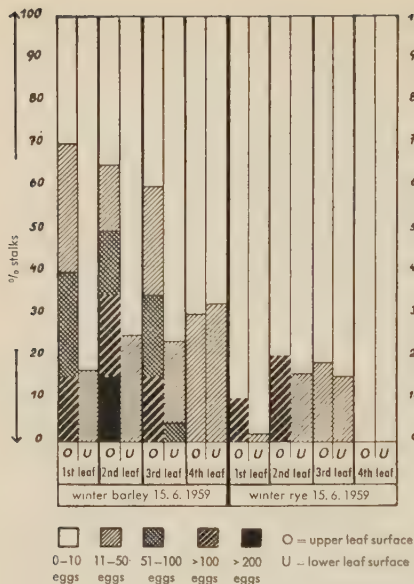


Fig. 9: Number of eggs per leaf on winter barley and winter rye in mixed crop

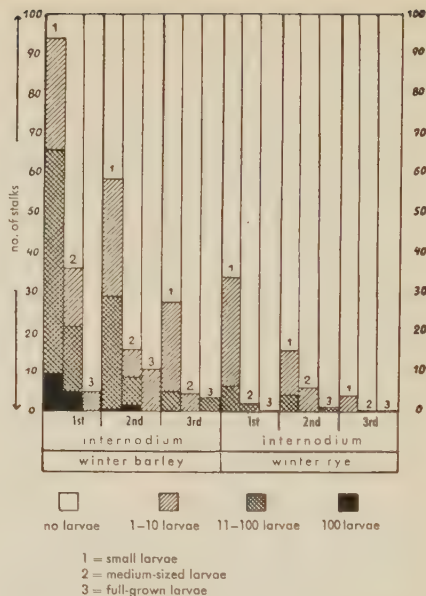


Fig. 10: Number and distribution of larvae in mixed crop of winter barley and winter rye on 18.6.1959

When *H. equestris* Wagn. occurs in masses, it lays its eggs preferably on cereal plants. The female adults very quickly find even isolated stalks in a grass crop. The midges have a marked power of selection when several cereal species are present in one crop. Barley and wheat were preferred in both 1958 and 1959. This was especially noticeable in fields with a mixed crop of rye and barley, or where wheat and barley were interplanted in a crop of rye or oats. Wheat and barley were always more severely infested than the other species (Table 1).

Fig. 9 provides a general indication of the abundance of eggs on winter barley and rye in a mixed crop, while Fig. 10 shows the distribution of larvae. On winter barley, the two top leaves were most severely infested with eggs. On the top leaves, the upper leaf surface is preferred by females but from leaf No. 4 the differences are not so marked. The absolute total number of eggs laid depends upon the population density of the adults. The large abundance of eggs on the 2nd leaf of winter barley (Fig. 9) clearly indicates a peak in the flight period. Colonization of rye in the same stand was considerably less. The egg density on the first leaf of rye is smaller than on the next two, this undoubtedly being due to the fact that the first leaf is much smaller and narrower; furthermore, in 1959 the first leaf had already started to wilt at the beginning of the flight period, due to the extremely dry conditions. The upper leaf surface is preferred for egg-laying also on rye and oats but this is not the case on wheat. The leaves of wheat plants are shorter and more upright than those of the other cereal species, so that eggs are laid in approximately equal numbers on both sides of wheat leaves.



Fig. 11: A striking symptom of infestation is swelling of the sheath



Fig. 12: Typical saddle galls

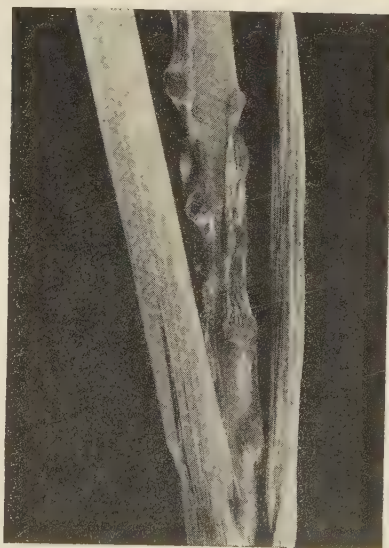


Fig. 13: Rot spreading from the edges of the saddle-like structures



## 2. Symptoms of infestation

A striking symptom of infestation is swelling of the sheath above the internodes (Fig. 11). When larval infestation is severe, the deep red-coloured larvae can be clearly seen through the raised, transparent-like sheath. The influence of infestation on stalk growth is reflected in the formation of galls; the size of these galls corresponds to the length of the larvae. The larva itself lies in a pit-like, extended hollow with irregularly thickened, wrinkled edges, running parallel to the axis of the stalk. This edge formation is clearly perceptible especially at the lower and upper end of the position where the larva has settled, and the entire structure has the appearance of a saddle (Fig. 12). The very thick edges of the "saddle" have a velvet-like surface, and are at first light yellowish, later changing to rather deep green as young stalk tissue forms. The saddle galls, however, have this typical structure only when infestation is moderate so that the positions of each larva remain isolated from one another. In the event of mass infestation, the edges of the individual recesses overlap, and the "saddles" lose their normal shape. In wet weather, dark-coloured fungus hyphae colonize the saddles; the residues of these remain clearly perceptible also after the stalk has turned yellow and dried up, when the actual peripheral tissue of the gall shrinks. The rot that sets in on the damaged parts in moist summer months, spreads from the soft peripheral zones (Fig. 13).

Stalks that are severely infested early in the season have a very retarded growth. Tillering of the affected plants either fails completely or is only partial. Stalks which are infested later in the season can hardly be distinguished from those not infested — apart from the swelling of the sheath — as long as the weather remains dry. But in wet weather, the infested parts soon begin to rot, with the result that many stalks crack.

Table 2: Distribution of larvae on the top three internodes of 190 winter barley stalks; counts taken at Laer, 1959

| Infested stalk section        | Number of stalks |          | %<br>infestation | Number of larvae<br>per internodium |         |
|-------------------------------|------------------|----------|------------------|-------------------------------------|---------|
|                               | not infested     | infested |                  | max.                                | average |
| 1st internodium<br>(from top) | 0                | 190      | 100              | 340                                 | 52      |
| 2nd internodium               | 65               | 125      | 65.8             | 255                                 | 22      |
| 3rd internodium               | 147              | 43       | 22.6             | 187                                 | 12      |

## 3. Distribution of larvae in the plant

In order to gain an indication of the infestation density, the numbers of larvae per stalk and per internodium were counted on winter barley on June 22, 1959 in a test field at Horstmar (Table 2). The maximum number counted in

one internodium was larger than quoted for cereals in the literature. A maximum of 340 larvae were found in one single internodium, and it was by no means seldom to count more than 100 larvae, usually in the first (from the top) internode. In 1958 and 1959, infestation on cereals was usually confined to the upper internodes, and occasionally occurred on the fourth but very seldom on the fifth stalk section. A comparison of the top three stalk sections shows that the largest number of larvae were always to be found in the 1st internodium, this number decreasing lower down the stalk.

This decrease in stages in the number of larvae is due to several factors, an important one being the dependence upon the strength of the midge flight, which in turn depends upon the weather. The density of the adult population in a certain period can be well estimated from the rate of egg-laying on the top leaves in the flight season, to which the abundance of larvae in the respective internodium also corresponds. (Fig. 10). The growing grain is colonized with eggs laid in tiers by the flying imagines.

A steady decrease in the number of larvae between the upper and lower internodes is also brought about by the death of a large number of the insects during the course of their development due to lack of living space or food. Despite a large initial abundance of young larvae, only relatively few full-grown larvae are found later. The question still remains to be settled whether the rate of mortality varies in the different sections of the stalk. The fact that different stages of larval development may be present in each internodium may be accounted for by the prolonged period of oviposition and by the marked irregularity in the growth of the larvae so that individuals of equal age are not always of the same size.

## V. Economic importance

The extent of damage caused by infestation of cereals with larvae of *H. equestris* Wagn. especially depends upon the time of infestation and upon the weather conditions prevailing at the time of larval feeding. All results given in this section regarding the effects of infestation were obtained in the studies conducted in the summer of 1959, a season outstanding for its extremely dry weather and high temperatures. A statistical control of the results was carried out in every case by means of the t-distribution method and the  $\chi^2$ -method (Linder, 1951), to preclude false conclusions being drawn, which may have been very easily possible in view of the unusual growing conditions.

### 1. Influence on growth of cereal plants

#### A. Early infestation

In the event of very early, mass infestation, the stalks may be so heavily colonized and weakened that their growth is stunted and the plants fail to head. Such extreme cases were encountered at two sites of infestation in 1959. Near Nordkirchen, a field of winter barley (Breustedt's Atlas variety) — its location was protected from the wind, and very warm; the previous crop grown here was wheat — was so heavily colonized with eggs laid during mass attacks of flying *H. equestris* Wagn. in late April and the first few days of May, that by the end of May there was an average of 200 to 300 larvae on each internodium. In fact in this field, there were no stalks at all which were not infested. 29 % of the ears were stunted. As there was no "non-infested" check available

for comparison, the harvest loss had to be estimated. Allowing for all circumstances, this loss must have amounted to about 40 %.

The devastating effect of early mass infestation proved to be even more pronounced in a field of winter wheat (Breustedt's Werla variety) examined at Herzfeld. As the result of a sudden rise of temperature at the beginning of the flight period, a mass attack of flying midges broke out at this location, and lasted only a few days (May 2 to 7); due to the subsequent encrustation of the soil caused by the drought, no more attacks took place. Nevertheless, several hundred eggs were laid on each wheat plant during this concentrated attack. The larvae, which were of almost equal length, had already completed their development by June 20, whereas in the infestation zone at Horstmar-Laer imagines were still flying at this time, and in addition to many full-grown larvae the population here consisted of all young larval stages. Out of 500 examined wheat stalks, ear growth was stunted on 182, more than 36 %. The other stalks were shorter than usual, and began to turn yellow already at the end of June. On June 23, 1959, the average length of these stalks was 43.37 centimetres, only about two-thirds the length of normal, healthy stalks of the same variety. It was, therefore, decided to burn the crop.



Fig. 14: An occasional external symptom of infestation is stalk bulging

## B. Infestation during the tillering stage

### a) Stalk length

Cereal stalks which were severely infested at the beginning of the tillering stage remained shorter than usual, this sometimes being externally perceptible in the form of bulging (Fig. 14)\*. The relation between longitudinal growth and

\* The illustrated infestation symptom occurred more frequently in 1960 than in 1959.



the degree of larval infestation was examined and registered for wheat (Carstens 6 variety), winter barley (Streng's Domina variety) and spring barley (Ackermanns Isaria variety). Practically all stalks in the fields (Horstmar) were infested so that apart from the very few non-infested stalks only those slightly infested (1 to 10 larvae) could be used as a basis for comparison. The results are based on the measurements of  $2-3 \times 100$  stalks. Halms colonized by more than 100 larvae were rated as being severely infested.

### Wheat

The average length (Table 3) of non-infested or slightly infested wheat stalks was 65.8 cm, and only 53.9 cm for severely infested stalks. This corresponds to an average stunting of about 18.1 % for longitudinal growth. An evaluation of the results obtained in another plot of the same field in fact revealed an average reduction of longitudinal growth amounting to 20.7 %. The differences in stalk length are statistically significant.

### Winter barley

Winter barley was already in the heading stage at the time of infestation. Therefore, no appreciable influence on longitudinal growth was expected. Accordingly, the difference in the average lengths of slightly and several infested stalks, measured at 83.01 (84.3) cm and 82.4 cm, respectively, is not significant, being within the margin of natural variation.

### Spring barley

On spring barley, the average length of slightly infested stalks was 69.15 cm, and of severely infested stalks 64.86 resp. 60.38 cm. Thus the stunting of the longitudinal growth of the stalks averaged 6.2 and 12.7 %, respectively. The established differences are statistically significant.

Table 3: Relation of stalk length to infestation. Test conducted at Horstmar, evaluated on July 6, 1959

| Cereal        | Average stalk length     |                      |                      |
|---------------|--------------------------|----------------------|----------------------|
|               | No or slight infestation | Severe infestation   |                      |
|               |                          | 1st plot             | 2nd plot             |
| Winter wheat  | 65.8 cm<br>(= 100 %)     | 53.9 cm<br>(81.9 %)  | 52.18 cm<br>(79.3 %) |
| Winter barley | 83.01 cm<br>(= 100 %)    | 84.3 cm<br>(101.6 %) | 82.4 cm<br>(99.3 %)  |
| Spring barley | 69.15 cm<br>(= 100 %)    | 64.86 cm<br>(93.8 %) | 60.38 cm<br>(87.3 %) |

Summarizing, it may be concluded that the effect of larval infestation on longitudinal growth of stalks was greatest on winter wheat. The reason for this may be attributed to the fact that the main egg-laying period of *H. equestris* Wagn. and feeding by larvae occurred when the wheat plants were in a very early stage of growth (start of tillering). Development of spring barley, however, was much further advanced at this time so that growth stunting was much less. Winter barley plants had already grown to their final height by the time of the main, influential egg-laying season so that even severe larval infestation was no longer able to affect longitudinal growth of the stalks.

The results were confirmed by a parallel and more exact evaluation in which the value for the total infestation in the stalk was obtained from the varying degree of infestation on the internodes. The degree of larval infestation in an internodium was classified in the ratings 0, 1, 2, 3 and 4, whereby 0 means no infestation and 4 very severe infestation (over 100 larvae per internodium). The top three internodes were evaluated since it is only these which are essentially attacked. The values separately obtained for each of the three internodes were added.

Their total gave the value for the degree of larval infestation in the stalk, which was between 0 and 12 applying the given method of evaluation. In cases where severe larval infestation of a stalk had affected its growth, the short stalks had high values and the long stalks low values. The evaluation of a few plots by this method to control the above results, confirmed them. In the wheat and spring barley crops, the short stalks almost exclusively had high values (10—12), long stalks low values (0—5), and stalks of medium length had middle values (6—9). Once again, no significant differences in stalk length were established between the different groups of infestation density in the winter barley crop.

#### b) Length of spikes

Heading was expected to be influenced only following very early infestation. Usually, the spikes have already reached such an advanced stage of deve-

Table 4: Relation of spike length to infestation. Test conducted at Horstmar, evaluated on July 6, 1959

| Cereal        | Average spike length     |                    |
|---------------|--------------------------|--------------------|
|               | No or slight infestation | Severe infestation |
| Winter wheat  | 5.5 cm<br>(100%)         | 5.4 cm<br>(98.2%)  |
| Winter barley | 5.9 cm<br>(100%)         | 5.8 cm<br>(98.3%)  |
| Spring barley | 6.0 cm<br>(100%)         | 6.5 cm<br>(108.3%) |

lopment by the time *H. equestris* Wagn. lays its eggs that although their supporting stems are greatly affected by larval infestation, the spikes themselves are not. This was confirmed in comparative studies on the relation of spike length to degree of larval infestation in stems supporting the spikes on winter wheat, winter barley and spring barley (Table 4).

There was no significant difference in spike length for non-infested, slightly infested and severely infested spike stems on winter wheat, winter barley and spring barley. The degree of larval infestation on a stem thus had no influence on the longitudinal growth of spikes. The established differences between both groups of infestation density (no or slight infestation and severe infestation) are within the margin of variation for the examined crop. This result was confirmed by the evaluation carried out according to the same method employed for measuring stalk length.

### c) Grain development

In order to establish the influence of the larval population in the stem on grain development, the numbers of fully developed and empty grains per head were compared on winter wheat, winter barley and spring barley, for non-infested or slightly infested and severely infested stems (Table 5).

Table 5: Relation of grain development to infestation. Test at Horstmar, evaluated on July 15, 1959

| Cereal        | Average number of kernels and grains per head |                  |                  |                    |                  |                  |
|---------------|-----------------------------------------------|------------------|------------------|--------------------|------------------|------------------|
|               | No or slight infestation                      |                  |                  | Severe infestation |                  |                  |
|               | Kernels                                       | Full-grains      | Stunted grains   | Kernels            | Full-grains      | Stunted grains   |
| Winter wheat  | 64.9                                          | 39.2<br>(60.4 %) | 25.7<br>(39.6 %) | 61.6               | 32.4<br>(52.6 %) | 29.2<br>(47.4 %) |
| Winter barley | 49.3                                          | 37.3<br>(75.7 %) | 12.0<br>(24.3 %) | 48.4               | 34.9<br>(72.1 %) | 13.5<br>(27.9 %) |
| Spring barley | 20.4                                          | 17.6<br>(86.3 %) | 2.8<br>(13.7 %)  | 20.8               | 15.4<br>(74.0 %) | 5.4<br>(26.0 %)  |

### Winter wheat

Heads of severely infested winter wheat stalks contained 52.6 % fully developed grains and 47.4 % stunted grains, heads of slightly infested stalks contained 60.4 % fully developed grains and 39.6 % stunted grains. The percentage of fully developed grains in heads of severely infested stalks was accordingly 7.8 % lower on the average.



### Winter barley

Heads of severely infested stalks contained an average of 72.1 % fully developed grains and 27.9 % stunted grains, on slightly infested stalks an average of 75.7 % fully developed grains and 24.3 % stunted grains, in other words 3.6 % more full grains.

### Spring barley

Heads of severely infested spring barley stalks contained 74 % normally developed grains and 26 % stunted grains. Comparison heads of slightly infested stalks, on the other hand, had 86.3 % normally developed grains and 13.7 % stunted grains, in other words 12.3 % more full grains.

A check on the differences for significance revealed that the established difference between the numbers of fully developed grains on slightly infested and severely infested stalks is statistically significant only for winter wheat and spring barley. On winter barley, there was no genuine relation between the number of developed grains of a head and the larval infestation of the stalk bearing the head. This corresponds to the results obtained comparing the stalk lengths.

Although the spike length on winter wheat and spring barley was not influenced by infestation, weakening of the stalk nevertheless affected development of the grain. The cause of this might be attributed to ligature or constriction of the vessels supplying the affected grains, and indirectly to excessive strain on the stalk as the result of gall formation.

#### d) Comparison of yield on basis of "thousand grain weight" (TGW)

On August 1, 1959, the TGW of heads on non-infested and severely infested stalks was determined for winter wheat and spring barley growing at Horstmar. Corresponding controls of winter barley could not be carried out because

Table 6

| Tests at Horstmar 1959                                   | Degree of stalk infestation |               |              |               | Difference slightly-severely infested |               |
|----------------------------------------------------------|-----------------------------|---------------|--------------|---------------|---------------------------------------|---------------|
|                                                          | slight                      |               | severe       |               | winter wheat                          | spring barley |
|                                                          | winter wheat                | spring barley | winter wheat | spring barley |                                       |               |
| Average number of fully developed grains per head        | 39.2                        | 17.6          | 32.4         | 15.4          | + 6.8                                 | + 2.2         |
| Average number of heads needed to yield 1000 full grains | 25.5                        | 56.8          | 30.9         | 64.9          | — 5.4                                 | — 8.1         |

significant differences would not have been obtained in view of the results given above.

#### *Winter wheat*

1000 wheat grains from heads of severely infested stalks weighed 53.22 g; 1000 grains from heads of non-infested or slightly infested stalks weighed 54.86 g. The difference is significant. The calculation of the yield loss is based on the given significant differences in the number of fully developed grains from non-infested (or slightly infested) stalks and severely infested stalks. The yield decrease caused by severe infestation averaged about 20 % for the tests at Horstmar.

#### *Spring barley*

The thousand grain weight for spring barley amounted to 49.41 g for heads of non-infested or slightly infested stalks, and to 47.43 g for heads of very severely infested stalks. The difference is significant. The yield decrease was determined in the same way as for wheat, and was calculated at about 16 %.

Summarizing, the following conclusions may be drawn from the stalk studies. The critical infestation stage in all weathers is just prior to and at the start of tillering. When infestation occurs later, the extent to which growth and grain development are affected is all the less the more advanced is the development of the stalk. When the plants have headed, there will be little or no yield decrease even if infestation is severe at this time, provided certain weather conditions do not prevail, which we shall now discuss.



Fig. 15: Barley stalk completely rotted at the site of infestation

## 2. Influence of weather on scale of damage

Dry weather that persists for a lengthy period before emergence and during the flight season stimulates mass flights. When it rains after such a dry period so that the pupae, about to emerge, can force their way upwards through the now soft soil, adults will suddenly appear in great abundance, and the number of eggs laid will be correspondingly high. If such a flight peak in dry weather occurs at the start of the flight season, severe early infestation will result, which will have an even greater devastating effect since the growth of the plants is checked anyway after dry periods. Thus severe damage may be especially attributed to mass flights very early in the season.

Moist or wet, rainy weather, even when infestation is moderate, may lead to serious yield losses in that the infested parts of the stalks become colonized with rot fungi and mites, so that they then crack or rot completely (Fig. 15). This was often observed in the wet year of 1958. In the infestation zone of Laer-Horstmar, up to 60 % of the stalks had cracked or were completely rotten in some fields which seemed as if they had been struck and damaged by a hail-storm. The yield loss, although indirect but determined on the basis of reliable data, was about 20 % for winter wheat, at least 30 % for spring barley and approximately 15 % for oats.

## VI. Tests on the effect of insecticides

### 1. Preparatory work

A group of fields near Laer, surrounded on all sides by deciduous woods, was selected as a very suitable site for these tests. All the cereal crops growing here had been severely infested in 1958. In order to establish the density of the larval and pupal population, numerous specimens of soil measuring  $10 \times 10$  cm were dug out to a depth of 15 cm, and examined. Larvae and pupae of *H. equestris* Wagn. can be washed out of the soil in the same manner as larvae of the wheat midge but the larval chambers are destroyed in the process. Preference was, therefore, given to the practice of picking out the larvae and pupae especially as this method enabled a better assessment to be made of the position of the individuals in the soil and their stage of development. The soil samples taken from the areas selected for the tests contained on the average about 200 larvae (85 to 90 %) and pupae (10 to 15 %). The mass of large larvae and the pupae was situated immediately below the ground surface, and some lay exposed in the topsoil.

In April, several emergence cages measuring about  $1\frac{1}{2}$  square metre and covered with gauze, were set out in the test area at points where severe larval infestation had been observed, for the purpose of exactly establishing the start of the midge flight. It was later found that imagines in the test cage appeared at the same time as midges emerged in the fields.

The flight of the adults commenced on May 8, and continued on a considerable scale until May 12. Egg-laying was generally observed from May 9 onwards. The mass flight lessened somewhat about May 15. On May 26 as winter rye started to bloom and winter barley was about to flower, numerous imagines were, however, still laying eggs. The flight suddenly ceased after May 29, and on June 2 there were no more live midges to be found. The short period of rainfall that set in soon afterwards initiated another brief flight of numerous midges from June 8 to 12, for as a result of the moisture the



incrusted soil surface had become soft, facilitating emergence. Alternating dry and wet conditions continued to have a decisive bearing on the population density of the imagines, and after another pause it was again observed that large numbers of eggs were laid from June 21 onwards, but oviposition then finally terminated around June 29. By this time, most of the larvae that had emerged from the eggs laid in early May were full-grown, and left the stalks in masses as the plants finished maturing.

## 2. Products

In view of all the data that were known on the biology of *H. equestris* Wagn., preventive applications of contact insecticides against adults and young larvae still exposed on the foliage held the greatest promise of success. Active materials with good initial toxicity and a long residual action seemed most suitable, for the flight period is very prolonged so that continual egg-laying and emergence of larvae had to be reckoned with. From the group of chlorinated hydrocarbons, one product each was selected based on lindane-dichlorodiphenyltrichloroethane, lindane-dichlorodiphenyltrichloroethane-diieldrin and endrin. The trichloro-oxyethyl dimethylphosphonate product DIPTEREX® was of interest to us for its systemic effect on mining Diptera larvae, and dimethylmercapto-phosphate (METASYSTOX®) for its systemic action.

## 3. Equipment

The importance of the application method was also examined for lindane-dichlorodiphenyltrichloroethane. Use was made only of appliances which are actually employed in the field for treating cereal crops in various stages of growth (plant height). Suspensions and emulsions were sprayed from a horse-drawn sprayer at a rate of 600 litres/hectare, and atomized by a knapsack motor-powered atomizer at a rate of 150 litres per hectare. A knapsack combined appliance was used for cold-fog applications; the same appliance was also used for applying dust.

## 4. Method

Considering all probabilities, and assuming an egg diapause of 6 to 8 days, it was decided that the most suitable date for the first treatment would be May 15, especially as this date appeared early enough for controlling even the first hatching larvae. Test B, described here in more detail by way of example, was carried out in a mixed crop of winter rye and winter barley. As the density of the larval population in the peripheral zone of the field was particularly large, the test plots (3 × 600 sq. metres, each 20 × 30 metres) were divided off in such a way that they extended into the grainfield to a depth of only 30 metres.

The crop was about 60 centimetres high on the date of the treatment, and the stalks were in the tillering stage. The plants were, therefore, already in full foliage, and were largely in the process of heading. Large numbers of eggs were present on both species of cereals, the number being extremely high on barley. No difficulties were encountered with the technical application of the products, and the treatment was carried out in sunny, cloudy weather.

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## 5. Evaluation

On June 18, 100 stalks of rye and barley were sampled from each of the three plots, and the number of larvae per stalk was counted for each cereal species, records also being noted of the stage of growth and the colonization of each individual internode.

In evaluating the tests, careful consideration must be given to the mode of life and the development rhythm of *H. equestris* Wagn. An essential factor is that the main bulk of the eggs is usually deposited on the top leaf at the time of laying. When test B was carried out, leaf formation was already completed on winter barley so that the top leaf was in actual fact the final top one, in other words no more leaves would grow above it later, and consequently, most of the youngest egg pods were deposited on this particular leaf.

The eggs laid earlier on older leaves which were now well down the plant, had already advanced considerably in their development by the time the test was started, and in fact larvae had already hatched out of some of them. Even when allowance is made for an average egg diapause of 6 to 8 days, and for the fact that the young larvae may take 1 or 2 days to migrate from the site of oviposition to the sheath, it could safely be assumed that at the time of the test, apart from the presence of eggs and migrating young larvae, a number of

Table 7: Infestation of *H. equestris* Wagn. larvae in 3 uppermost internodes, based on average of  $3 \times 100$  barley stalks, following single application of insecticides by atomizing method, at a rate of 150 litres of spray solution per hectare. Treatment on May 15, 1959; evaluation on June 15, 1959, Test B

| Active material<br>Formulation<br>Active ingredient content | Pro-<br>duct | Applied<br>conc.<br>in % | Number of stalks<br>in every 100 infested<br>in internode |    |     | % decrease in number<br>of infested stalks in<br>comparison with<br>untreated check in<br>internode |      |      |
|-------------------------------------------------------------|--------------|--------------------------|-----------------------------------------------------------|----|-----|-----------------------------------------------------------------------------------------------------|------|------|
|                                                             |              |                          | I                                                         | II | III | I                                                                                                   | II   | III  |
| Lindane + DDT<br>Suspension<br>2.25 % + 35 %                | M            | 0.8                      | 42                                                        | 9  | 1   | 55.8                                                                                                | 86.6 | 95.8 |
| DIPTEREX<br>Soluble powder<br>50 %                          | D            | 0.4                      | 44                                                        | 18 | 3   | 53.7                                                                                                | 73.1 | 87.5 |
| Lindane + DDT + dieldrin<br>Emulsion<br>8 % + 20 % + 8 %    | M 3          | 0.2                      | 75                                                        | 36 | 12  | 21.1                                                                                                | 46.3 | 50.0 |
| Endrin<br>Emulsion<br>50 %                                  | E            | 0.2                      | 97                                                        | 70 | 23  | 0                                                                                                   | 0    | 4.2  |
| METASYSTOX<br>Emulsion<br>25 %                              | MS           | 0.4                      | 88                                                        | 65 | 22  | 7.4                                                                                                 | 3.0  | 8.3  |
| Untreated check                                             | —            | —                        | 95                                                        | 67 | 24  | —                                                                                                   | —    | —    |

larvae had already penetrated into the space between the stalk and the sheath. This assumption was confirmed by checks of the different internodes, for in the 3rd internode larvae were found which, although always isolated, were already relatively large. These few large larvae that originated from very early infestation could, however, be disregarded in the evaluation. On the other hand, eggs were continually laid also after the products had been applied, and it was from these eggs that the small larvae originated which were present at the time the tests were evaluated.

Chief consideration was given to the 1st (uppermost) internode for assessing the residual effect of a product. A more or less large number of very young larval stages were found in the 1st internode, as expected, four weeks after the treatment. This enabled a reliable assessment to be made of the persistence of the products used. In order to assess the initial toxicity, however, the infestation in the 2nd internode was evaluated for appreciable subsequent egg-laying did not have to be reckoned with in this internode.

## 6. Results

The results in Table 7 show that the lindane + DDT product M, applied once, gave the largest decrease in infestation. The second best effect was produced by the phosphonic ester D. The weaker effect of the lindane + DDT + dieldrin preparation M 3 may be mainly accounted for by the fact that the residual action of the emulsion (smaller DDT content) was less persistent than for the lindane + DDT suspension M, and thus the contact effect was inadequate. The addition of dieldrin did not strengthen the effect for the larvae were not controlled until they had penetrated into the space between the leaf sheath and stalk. No contact effect was perceptible for the endrin product E, and a stomach poison action is out of the question. The systemic product MS did not have any appreciable effect, either.

In parallel tests at an earlier date (treatment on May 10, 1959), the decrease of infestation in the 2nd internode was 4.4 % greater for the lindane + DDT product M, and 3.2 % greater for the phosphonic ester D. This percentage gives an indication of the slight degree of early infestation no longer present at the time of the treatment on May 15. Following the replicated treatment of half of the plots in Test B on May 26, the increase in the percentage of old larvae killed in the 2nd internode amounted to 6.3 % for the lindane + DDT product M, and to 5.1 % for the phosphonic ester product D. The mortality rate for very young larvae, as expected, was considerably higher. The total decrease in the 2nd internode was accordingly 91.1 % for product M, and 86.7 % for product D.

In Table 7, only the number of barley stalks infested in internodes 1 to 3 (in %) is given. This figure, however, does not provide any indication of the distribution of the larvae according to their different stages (age groups), so that the same barley stalks were again evaluated to obtain this information (Table 8). The development stages of the larvae are given only in three sizes, namely small, medium-sized and large. In order to avoid errors arising out of extreme numerical values, the evaluation was confined to stalks with moderate infestation, 10 to 100 larvae per internode being taken as a standard.

By far the greatest percentage of larvae in all internodes are the youngest stages, although there is a staggered decrease in their numbers from internode 1



Table 2: Distribution of larval stages in stalks with moderate infestation (10 to 100 larvae per internode), after single application of insecticides by atomizing method, Test B

| Active material<br>Formulation<br>Active ingredient content | Commercial<br>product<br>used | Applied<br>conc.<br>in % | Internode | Number of stalks in every 100 with moderate<br>larval infestation, that were colonized by |                         |              | % stalks<br>with<br>moderate<br>infestation |
|-------------------------------------------------------------|-------------------------------|--------------------------|-----------|-------------------------------------------------------------------------------------------|-------------------------|--------------|---------------------------------------------|
|                                                             |                               |                          |           | small larvae                                                                              | medium-<br>sized larvae | large larvae |                                             |
| Lindane + DDT<br>Suspension<br>2.25 % + 35 %                | M                             | 0.8                      | I         | 29                                                                                        | 2                       | 1            | 32                                          |
|                                                             |                               |                          | II        | 4                                                                                         | 5                       | 0            | 9                                           |
|                                                             |                               |                          | III       | 0                                                                                         | 0                       | 0            | 0                                           |
| DIPTEREX<br>Soluble powder<br>50 %                          | D                             | 0.4                      | I         | 28                                                                                        | 6                       | 0            | 34                                          |
|                                                             |                               |                          | II        | 11                                                                                        | 5                       | 0            | 16                                          |
|                                                             |                               |                          | III       | 2                                                                                         | 0                       | 0            | 2                                           |
| Lindane + DDT + dieldrin<br>Emulsion<br>8 % + 20 % + 8 %    | M 3                           | 0.2                      | I         | 44                                                                                        | 9                       | 0            | 53                                          |
|                                                             |                               |                          | II        | 12                                                                                        | 5                       | 0            | 17                                          |
|                                                             |                               |                          | III       | 7                                                                                         | 0                       | 0            | 7                                           |
| Endrin<br>Emulsion<br>30 %                                  | E                             | 0.2                      | I         | 73                                                                                        | 6                       | 1            | 80                                          |
|                                                             |                               |                          | II        | 35                                                                                        | 2                       | 0            | 37                                          |
|                                                             |                               |                          | III       | 8                                                                                         | 0                       | 0            | 8                                           |
| METASYSTOX<br>Emulsion<br>25 %                              | MS                            | 0.4                      | I         | 59                                                                                        | 13                      | 0            | 72                                          |
|                                                             |                               |                          | II        | 25                                                                                        | 2                       | 1            | 28                                          |
|                                                             |                               |                          | III       | 4                                                                                         | 0                       | 0            | 4                                           |
| Untreated check                                             | —                             | —                        | I         | 64                                                                                        | 19                      | 8            | 91                                          |
|                                                             |                               |                          | II        | 38                                                                                        | 10                      | 2            | 50                                          |
|                                                             |                               |                          | III       | 10                                                                                        | 4                       | 0            | 14                                          |

(top) to internode 3. Thus., it is again proved that eggs were laid several times in the period between the treatment and the evaluation. This is clearly evident from the decrease in the number of larvae corresponding to the residual effect of the product.

The following reductions in infestation were registered in the 1st internode against larvae that occurred later: 54.7 % for product M, 56.3 % for product D, 31.3 % for product M<sub>3</sub>. In the 2nd internode, the difference is reflected in the initial toxicity of the products for few larvae appear from eggs laid later: — for product M the infestation decrease is 89.5 %, for product D 71.1 %, and for product M<sub>3</sub> 68.4 %.

It is obvious from these figures that the effect of the tested products on adults and especially young larvae that migrate exposed on the leaf down to the ligule, is limited. The main effect is unfolded on the ligule itself and in the "entry hole" leading into the sheath for it is here that the larvae remain for a lengthy period, and moreover it is just at this point that a concentrated reservoir of insecticide is formed by rolling droplets of spray solution and active ingredient washed down by rain. The fact that larvae which had already penetrated deeper into the space between the sheath and the stalk were not controlled by any of the applied products, is demonstrated by the number of medium-sized and large larvae still present, which originated from early infestation.

A lengthy discussion of the other tests is not possible due to lack of space so that their results will be summarized in the following section on suggestions for control.

## VII. Suggestions for control

### 1. Forecast of infestation

The abundance of adults expected in a limited area can be determined in March/April with considerable reliability by taking soil samples in wheat or barley fields infested the preceding year. If more than 50 larvae are found on the average in a section measuring 10 × 10 cm dug out down to a depth of 15 cm, careful attention must be given to the situation. When digging out and evaluating soil samples, allowance must be made for the fact that a very large number of larvae gather in the soil at places where sheaves were stacked in the previous year's harvest. This may easily lead to wrong conclusions being drawn as to the real population density.

A further possibility of ensuring that correct forecasts are made is to observe the first midge flight. The intensively coloured adults are noticed even by untrained observers. However, as the emergence of the midges depends upon the weather, frequent checks of the grainfields from late April onwards must be carried out in order to guarantee that unusually severe occurrence will be observed early enough. When an average of 3 to 5 midges are laying eggs on 10 cereal stalks, this is an indication that the situation may become serious. General forecasts for large areas attach little value for the population density of the midges greatly varies even in a small space.

### 2. Warning service

In places where *H. equestris* Wagn. has already occurred, the competent crop protection office should draw the attention of local farmers and growers

to the pest at the end of April by making announcements over the radio and in the press. Inter-area warning announcements are suitable only for general orientation. They should be so worded that the farmer does not interpret them as a demand to carry out controls. Experience accumulated in the publicity of control drives against wheat midge has shown that the danger may easily arise of causing uneasiness among farmers in areas that are not affected.

The farmers should first be asked only to keep a check on their grainfields. The necessity of a chemical control of *H. equestris* Wagn. can only be judged by an expert.

### 3. Crop rotation

As *H. equestris* Wagn. attacks only cereals and other gramineae, the pest can easily be eliminated in limited areas by crop rotation (root crops, oil-seeds, field vegetables). Cereals should not be set as the next crop in severely infested fields. Furthermore, farmers are advised at least not to sow wheat and barley in the immediate vicinity of an infested field.

### 4. Chemical control

Insecticides with a long residual action are the only chemicals suitable for controlling *H. equestris* Wagn. Adequate initial toxicity is also desirable. Considering that the mass flights are sometimes concentrated within a period of a few days, rapid eradication of the adults is very important for they copulate immediately after emerging and then begin at once to lay eggs.

Dusts are not recommended for controlling *H. equestris* Wagn. because of their short action. Spraying proved to be a very suitable method of applying effective products during the dry year of 1959. This method guarantees adequate distribution of the spray solution, maximum throw and penetration into the crop even on hot days, and full coverage of the plants. Even during the spraying operation, a considerable concentration of active ingredient is brought about by the droplets rolling down into the ligule, which is later strengthened when rain falls and washes down parts of the spray deposit that is not especially resistant to rain. Young larvae that migrate from the leaf surface remain on the ligule for a lengthy period.

The use of large sprayer machines in growing crops of cereals is, however, known from experience to meet with objection from farmers unless this work can be done so early that controls of *H. equestris* Wagn. can be combined with weed-killing (spring cereals). In addition, supply and cartage of water is a difficult problem in some regions. Therefore, special emphasis should be laid on the suitability of the atomizing method for controlling the pest, this having been proved in corresponding trials. However, a well-distributed deposit of insecticide on the cereal plants can only be obtained with atomizers on hot days provided the treatment is carried out in the early morning hours or in the evening. Another favourable factor is that the atomized deposit is not so resistant to rain that a part of the insecticidal deposit cannot be washed down into the ligule.

The use of fog applicators in 1959 was not very encouraging. The high temperatures made it impossible to obtain adequate distribution of the fog in the crop and thus to give the plants full coverage. But even in years of normal temperature conditions, it is unlikely that the fogging method will attach the



same importance for controlling *H. equestris* Wagn. that it has in operations against wheat midge. The high resistance of fog deposits to rain is a disadvantage in operations against *H. equestris* Wagn. because the application of chemicals for controlling this pest is only purposeful at a time when the cereal stalks are still vigorously growing. But this means that spaces rapidly form in the deposits of insecticide, and if this is not compensated for by a subsequent "new distribution" brought about by rain and dew, then there will be a rapid decrease of effect. Conditions in the control of *H. equestris* Wagn. are more complicated than those encountered in measures against wheat midge; the flight of the wheat midge is much shorter. The growth of the cereal plants, however, is so far advanced, in fact almost completed, at the time of the wheat midge flight that the insecticidal deposit on leaves and stalks will later not break up very much. At all events, the results of *H. equestris* Wagn. controls in 1959, obtained for applications of insecticides by the cold-fog method, were not so good as those registered with sprayers and atomizers.

### Timing of controls

Generally valid dates for the application of insecticides against *H. equestris* Wagn. cannot be given because timing depends too much on local conditions. Chemical controls are indispensable in areas infested the previous year, and where it has been found unavoidable to grow cereals again as the next crop. The midge flight and intensity of egg-laying must be carefully observed so that decisions can be reached from case to case whether a control is advisable at the current stage of plant growth. Chemical controls are recommended in cases where winter cereals are threatened very early in the season by mass infestation or where the spring cereals appear to be endangered by heavy, staggered midge flight. In winter cereal crops, a single control before or at the beginning of the tillering stage will usually be sufficient, and in crops of spring cereals where the first treatment should be carried out after the plants have completely tillered, the treatment can be repeated after 2 to 3 weeks. Rye and oats need only be treated in exceptional cases.

### VIII. Summary

1. *Haplodiplosis equestris* Wagn. occurred in 1958 and 1959 in Westphalia on cereals growing on heavy loam and clay soils, causing severe damage.
2. The morphology of the different instars is described. The first adults appeared in early May in 1959. The midge flight continued until late June, with interruptions caused by the weather.
3. Eggs are laid in pods on the leaves of cereal plants. The young larvae migrate to the ligule where they enter the space between the stalk and sheath. Their development lasts 3 to 4 weeks. After the stalks have passed maturity, the larvae fall to the ground, and crawl into the soil where they overwinter. Pupation takes place in spring. Larvae are known to remain in the same instar for at least one year.
4. Wheat and barley are preferred as host plants. The most important symptoms of infestation are swelling of the stalks and formation of saddle-shaped galls.

5. The growth of cereal plants is influenced by larval colonization to an extent depending upon infestation density and the time of infestation. Early infestation that occurs before the plants tiller may result in severe damage.
6. When the plants are colonized by larvae while they are tillering, elongated growth of the stalks is reduced and the development of the grains in the heads is affected. Late infestation in normal weather conditions causes no significant harm.
7. In wet years, severe yield losses may result even when larval infestation is moderate because then rot develops on the infested plant parts causing the stalk to crack and stoop. The most important counter-measure that can be taken in infested fields is to avoid planting cereals and other gramineae for the next crop.
8. A reliable forecast of forthcoming infestation is possible by examining soil samples for larval colonization. Warning announcements attach importance only for limited areas because changes in population density are greatly influenced by local factors.
9. Insecticides with a good residual action are suitable for controlling *H. equestris* Wagn. In trial applications of lindane + dichlorodiphenyltrichloroethane and DIPTEREX on winter cereals, a single treatment gave adequate reduction of infestation.
10. Application of the test products by means of sprayers and atomizers proved to be most effective. The use of the cold-fog method was less successful. Dusts gave an unsatisfactory action.

## IX. References

A comprehensive list of old literature is given in the paper of Faber (1959) so that it will suffice here to give the references quoted in this paper.

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# Control of Late Blight of Potatoes (*Phytophthora infestans* [Mont.] de Bary) in Holland

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Late blight of potatoes (*Phytophthora infestans* [Mont.] de Bary) is one of the most important diseases occurring on agricultural crops in Holland. Despite intensive controls, heavy losses are still inflicted in some years. The average damage caused by this disease is estimated by Mastenbroek (4) at 20 million guilders (yield losses and costs of control operations); the figure quoted by van der Zaag (6) is in fact twice as high. The primary reason for this more or less disappointing result is that the disease must be controlled by preventive measures.

A fundamentally different method of control appears to be the only means of considerably reducing the annual losses. Alternatives that might be given consideration are the breeding of resistant varieties and the development of fungicides with a curative action. Of these, it seems that the former possibility offers the more favourable prospects, and in actual fact considerable progress has already been made in this sector. The repeated incidence of physiological strains of the fungus, which attack the originally resistant potato varieties, however, presents growers with very great difficulties in developing this practice.

The preventive control method incorporating cultural practices and application of crop protection products will, therefore, retain its present importance at least for the time being. Research in this direction is being forced ahead intensively, but as one might expect progress is being made only with much difficulty. In the following, a summarized report will be given on achievements that have so far been made to the benefit of growers.

## 1. Removal of infectors in spring

Van der Zaag (6) once again clearly demonstrated that the fungus overwinters almost exclusively in the tuber. Infected plants can develop especially from diseased tubers of sensitive varieties such as Bintje, Erstling and Eigenheimer, as shown in Table 1.

The first foci of infection can, therefore, be expected to be found especially among sensitive varieties. Refuse heaps of graded out potatoes also have great bearing as infection foci. It is here that the disease is usually first found as the result of the favourable microclimatic conditions prevailing among the numerous stems. The importance of tubers left in the field as a focus of infection has not been fully established but in all probability this is not very great.



*Table 1: Relation between the sensitivity of tuber and leaf and the percentage of secondary-infected plants (i.e. diseased plants infected from the tuber). Field test carried out at a mean soil temperature of  $\pm 10^{\circ}\text{C}$  (6).*

| Variety          | Sensitivity according to variety list of 1955* |      | No. of planted tubers | Percentage of emerged plants | Percentage of secondary-infected plants | Percentage of secondary-infected plants out of emerged plants |
|------------------|------------------------------------------------|------|-----------------------|------------------------------|-----------------------------------------|---------------------------------------------------------------|
|                  | Tuber                                          | Tops |                       |                              |                                         |                                                               |
| Eersteling       | 3                                              | 3    | 200                   | 61                           | 6                                       | 10                                                            |
| Saskia           | 5                                              | 4    | 270                   | 63                           | 7                                       | 11                                                            |
| Eigenheimer      | 3                                              | 5    | 300                   | 64                           | 3                                       | 4                                                             |
| Furore           | 5                                              | 8    | 300                   | 62                           | 2                                       | 3                                                             |
| Koopman's Blauwe | 8                                              | 3    | 300                   | 97                           | 3                                       | 3                                                             |
| Voran            | 7                                              | 7    | 300                   | 39                           | 0                                       | 0                                                             |
| Noordeling       | 8                                              | 7.5  | 300                   | 95                           | 0                                       | 0                                                             |

\* Low figure = high sensitivity.

The destruction of refuse heaps and the clearance of the first infectors in the field can, therefore, often delay disease incidence most appreciably provided these measures are generally carried out. However, the infectors in the field are usually discovered too late for adequate and economical measures to be taken. In such plots, the disease spreads slowly but surely even in weather conditions that are not so favourable for development of the fungus. The farmer must then attempt to check the damage as long as possible by repeated sprays of copper products. Tuber infection in such plots is usually very severe.

It is, therefore, of the greatest importance only to plant healthy seed. However, it is extremely difficult to sort out very easily infected tubers when grading.

## 2. Timing of first spray application

In timing the first spray application, a distinction must first be made between susceptible and moderately resistant varieties.

The first treatment of susceptible varieties should be carried out before the rows close up in order to ensure that the bottom leaves will also be given full coverage of spray solution, which means, therefore, that the biological behaviour of the fungus is not taken here as the deciding factor. We realise that this method is not completely satisfactory. In certain years, one would be able to start the treatment also at a later date. So an attempt was made to shed

more light on this situation by taking as the basis the activity of the fungus in the first foci. It could not, however, be proved that it is a safe procedure to take the activity of the fungus as the criterion for timing the first treatment.

It has been established that the first spraying of moderately resistant varieties, especially those growing in sandy soil, can be delayed until the disease occurs on susceptible varieties in the vicinity (see Table 2).

Table 2: Results of five tests on Voran variety with three treatments (date I, II and III) and two treatments (date II and III).

(Date I = when the rows close up; date II = upon incidence of disease on susceptible varieties; date III = approx. 16 days after date II.)

The tabulated figures are mean values; the plants treated with copper oxychloride at a rate of 10 kilos per hectare (de Lint).

|                                                              | Date of treatment |            |
|--------------------------------------------------------------|-------------------|------------|
|                                                              | I, II and III     | II and III |
| Mean values for leaf infection during season*                | 6.0               | 5.8        |
| Total tuber yield (kilos/are)                                | 416               | 428        |
| Tuber yield converted to submerged<br>weight = 400 in kg/are | 407               | 420        |
| Yield of healthy tubers > 35 mm in kilos/are                 | 380               | 392        |

\* The seasonal mean for leaf infection was calculated from weekly evaluations based on ratings 0 to 10 (10 = healthy, 0 = dead). The recorded ratings were added together and divided by the number of evaluations.

Although leaf infection can be controlled somewhat more effectively with three treatments, the tuber yield was higher in the two treatment tests (see Table 2). Similar results were also obtained on the table potato variety *Libertas* which is even less susceptible than the Voran variety with respect to both leaf infection and tuber infection.

Growers wishing to limit treatment of these varieties to a single spray application are advised to carry it out when the first infected leaves are observed in the plots; this remedy proved itself in 4 tests carried out in 1958.

### 3. Timing of subsequent sprays

Here, the most difficult problem is encountered in the control of *Phytophthora*. As the products only have a preventive action, a deposit of active ingredient must always be present on the leaf surface when sporulation takes place

and germination of spores is imminent. These processes, however, depend solely upon climatological conditions.

A large number of papers have been published dealing with the question under what conditions infections may be expected to occur. In this respect, reference may be made to the paper of Uhlig (5). The criteria established by the different authors have one point in common, namely that on the basis of these standards a critical period for *Phytophthora* cannot be established until an infection has already taken place, so that a preventive control can then no longer be considered. The value of such criteria is, therefore, rather doubtful for practical farming.

The following possibilities are open to growers for treating susceptible varieties:

- a) Periodical treatments, for example every 10 days. The disadvantage of this practice is that under certain conditions fewer sprays would also give adequate control, whereas in especially unfavourable conditions infections may occur despite so many treatments.
- b) Timing of treatments to coincide with favourable weather conditions. For this to be realised, it is essential to have reliable weather forecasts for a fairly long period. However, as the reliability of long-term weather forecasts often still leaves much to be desired, disappointments must occasionally be taken into account here.
- c) Very close spraying schedule, for example at intervals of one week. The large number of sprays which already amounts to 7 or 8 per season in procedures a) and b) without the factor of uncertainty being completely eliminated, now becomes so great that there may be doubt about the economy of the spray applications.

The above difficulties can only be surmounted provided the time can be determined at which the fungus forms spores but at which an infection of the

Table 3: Average results of two treatments (average dates of treatment July 19 and August 4, copper oxychloride at 10 kilos per hectare) in comparison with an untreated control. Average of 8 tests conducted on Voran variety in 1957 and 1958 (de Lint).

|                                                              | Untreated | Treated |
|--------------------------------------------------------------|-----------|---------|
| Mean leaf infection during season*                           | 4.3       | 5.8     |
| Total tuber yield in kilos per are                           | 370       | 417     |
| Tuber yield converted to submerged weight = 400 in kilos/are | 351       | 408     |
| Submerged weight in gr.                                      | 380       | 392     |
| Yield of healthy tubers > 35 mm                              | 330       | 379     |
| % diseased tubers                                            | 2.7       | 3.1     |

\* see footnote in Table 2.

plants has not yet taken place. Research that is in progress in this direction in Holland appears to hold much promise of success.

Moderately resistant varieties can usually be protected with two treatments; the interval between these treatments should be about two weeks on varieties like Voran, and approximately 18 days on varieties such as Libertas which are even less susceptible to leaf and tuber infection. Details of yield increases obtained following such treatment are given in Table 3.

The results given in Table 3 clearly show that as a result of carrying out two treatments with copper oxychloride, the total tuber yield can be increased by 47 kilos per are (100 square metres) or by 13 % as compared with the untreated control plot, and the submerged weight of the tubers by 12 grammes; the tuber infection in the treated plot was found, however, to be somewhat more severe.

#### 4. Crop protection products

For controlling late blight, copper products (copper oxychloride, copper oxycarbonate, copper oxide), zineb, maneb and organic tin preparations are available. Copper oxychloride and zineb are primarily used. Copper products given very good control of the disease but they may stunt plant growth somewhat. Although slight differences in effect exist among the named copper preparations, these have no real bearing on practical application. Zineb does not possess such a stunting action but is less effective against tuber infection. For treatment of varieties which are especially susceptible to tuber infection, a combination of the favourable properties of both products is sought, therefore, we found this in the spray schedule "two treatments with zineb, followed

Table 4: Average results of 16 tests on Bintje variety growing in loamy soil, from 1954 to 1958, comparing pure copper sprays, pure zineb sprays and the combined schedule of "two zineb treatments followed by application of copper". The average number of treatments amounted to 5.6 (de Lint).

|                                                                      | Leaf infection<br>mean seasonal<br>value | total     | Yield*<br>healthy tubers<br>> 35 mm | % of infected<br>tubers in<br>total yield |
|----------------------------------------------------------------------|------------------------------------------|-----------|-------------------------------------|-------------------------------------------|
| Copper oxychloride                                                   |                                          |           |                                     |                                           |
| 7—10 kilos/hectare                                                   | 7.6                                      | 108       | 121                                 | 7.7                                       |
| Zineb 3—5 kilos/hectare                                              | 7.1                                      | 113       | 119                                 | 13.4                                      |
| 2 X zineb at 3—4 kilos per hectare followed by<br>copper oxychloride |                                          |           |                                     |                                           |
| at 9—10 kilos/hectare                                                | 7.7                                      | 111       | 121                                 | 10.1                                      |
| Untreated (kilos/hectare)                                            | 4.3                                      | 100 (365) | 100 (278)                           | 17.2                                      |

\* Relative value untreated = 100.



by an application of copper" (1, 2, 3). Results obtained with this spraying schedule in comparison with pure copper spray applications and a schedule of pure zineb sprays on the Bintje variety, are given in Table 4.

It is evident from Table 4 that out of the products tested on loamy soil, zineb does not control leaf infection and especially tuber infection as well as copper oxychloride. Irrespective of the higher tuber yields in the zineb plots, there are smaller yields of healthy tubers over 35 mm in these plots. The spraying schedule "two zineb treatments followed by application of copper" gave just as good results as copper oxychloride itself for control of leaf infection. This spraying schedule also produced results just as good as those recorded for copper with regard to the yield of healthy tubers (> 35 mm). The advantage of the high tuber yield in this plot was lost, however, due to the more severe tuber infection recorded for the zineb-copper combination. On the grounds of these results we recommend that susceptible varieties growing on soil where severe tuber infection is possible, should be treated solely with copper products, or twice with zineb followed by application of copper.

If only slight tuber infection is anticipated (for example, on susceptible varieties growing on light sandy soil or on moderately resistant varieties), and in the event of the control being primarily directed against leaf infection, it is then recommended, on the other hand, to use only zineb (1, 2, 3), as indicated by Table 5 in which the results are given for tests conducted on the Bintje variety growing in sandy soil. Comparable results were obtained also for moderately resistant varieties on loamy soil.

Table 5: Results of *Phytophthora* tests on the Bintje variety growing in sandy soil; averages of 15 tests (de Lint).

| Product and dosage         | Yield in kilos/are |                        | % of infected tubers in total yield |
|----------------------------|--------------------|------------------------|-------------------------------------|
|                            | Total              | Healthy tubers > 35 mm |                                     |
| Copper oxychloride         |                    |                        |                                     |
| at 7—10 kilos/hectare      | 370                | 313                    | 2.2                                 |
| Zineb at 3—5 kilos/hectare | 402                | 337                    | 4.3                                 |
| Untreated                  | 335                | 274                    | 4.1                                 |

Copper products should be preferred on soil slightly or greatly lacking in copper, and on soil where there is a too vigorous growth of foliage.

Maneb is little used by growers. This product has an effect comparable with that of zineb so that the possibilities of application are about the same for both products. Application of maneb should, however, be given preference on soil lacking in manganese.

Relatively little experience has been accumulated on organic tin compounds. In tests carried out in 1957 and 1958, it was found that the products offer good prospects for the control of leaf rot and especially tuber rot. Their application may cause slight leaf burns; it was found, however, in the tests that were conducted that these burns did not result in yield reductions in healthy stands.

### 5. Haulm killing

Generally speaking, it is not possible by spraying to keep the plants completely free of infection until they ripen, although such applications do greatly slow down spread of the disease. Only slight leaf infection is needed for the tubers to be continually exposed to infections which are caused by spores emanating from the leaves, and therefore it is not recommendable to check leaf infection further by more frequent treatments on soil where no appreciable tuber infection is to be expected. On such soil, it is necessary to kill the tops when weather conditions are favourable to a further spread of the disease.

In order to establish the best time for carrying out haulm (top) killing, several tests were conducted from 1954 to 1957 (1, 2). In these tests, the tops were killed on plants with the following ratings: 9 (5 to 10 % of the plants infected with 1 to 5 diseased leaves per plant), 7 (relatively many, > 20 % of the plants infected with approx. 10 diseased leaves per plant) and 5 (almost every plant and nearly all leaves infected, the plants still appear green; on calm evenings, the disease "can be smelt"); the plants can grow normally in a part of the test field. The average results obtained in these tests are given in Table 6; these tests were divided up into two sections, namely moderate and severe tuber infection (< resp. > 100 kilos infected tubers per 100 square metres in the untreated control).

Table 6: Average results of tests for establishing suitable dates to carry out top killing on loamy soil, Bintje variety. The tests are divided up according to degree of tuber infection — moderate and severe.

|                                         | Weight of infected tubers in kilos/are |        | Yield of healthy tubers > 35 mm |        |
|-----------------------------------------|----------------------------------------|--------|---------------------------------|--------|
|                                         | moderate                               | severe | moderate                        | severe |
| Top killing for leaf infection rating 9 | 21.6                                   | 136.8  | 288                             | 216    |
| Top killing for leaf infection rating 7 | 27.5                                   | 159.6  | 301                             | 212    |
| Top killing for leaf infection rating 5 | 37.0                                   | 184.1  | 303                             | 312    |
| Tops not killed                         | 51.7                                   | 241.3  | 288                             | 163    |

It is evident from Table 6 that tuber infection is less severe the earlier the plant tops are killed. With moderate tuber infection, the maximum yield of tubers > 35 mm is obtained at a rating of 5 for leaf infection, whereas with severe tuber infection at a rating of 9. Growers must, therefore, be recommended to kill tops at a rating of about 7 on soils where more or less severe tuber infection is likely. In cases where plants have a vigorous growth of foliage, it may be advisable under certain circumstances to defoliate the plants somewhat before starting to kill the tops. A slight leaf infection spreads relatively quickly in such a stand even when the weather conditions appear to be unfavourable for it.

Top killing can be carried out with sodium arsenate or DNOC in oil. When applied on sandy soil, sodium arsenate may cause injuries to the crop planted after the potatoes. On loamy soil, however, such injuries need not be feared when the recommended dosage of 16 to 20 litres per hectare is applied.

## 6. Roguing

As a rule roguing should be carried out when the soil is rather dry. It has been established that the spores remain germinable in moist soil for a relatively long period (Van der Zaa g, 6), and may quite easily lead to tuber infections when roguing is carried out here. Attention must be given to this also when tops are killed.

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# Folidol® Oil for Controlling Red Spider Mite

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Control of fruit tree red spider mite is really no longer a problem for effective and persistent products are now available, which, when timely applied, will prevent the damage caused in the past by this pest. However, in a plum-growing area preference will nevertheless be given to those products which are effective against winter eggs of red spider mite, also for winter spraying of the fruit trees. This is necessary because when infestation is severe, considerable damage may be caused to leaves and buds in a warm spring already prior to and during the blossom, before post-blossom sprays suppress further development of red spider mite.

Trials conducted in previous years showed that DNOC tar oil does not give a high percentage kill of red spider mite winter eggs, even when the sprays are timely and thoroughly applied; on the contrary, the impression was gained that the effect rathermore tends to retard emergence of larvae. Far more favourable experience was gained with DNBP. Spraying of this product can be delayed in fact until shortly before the flower buds appear, when the red spider mite larvae usually begin to hatch out of the winter eggs.

In order to check previous test results, a trial was carried out in spring, 1959, in which plum trees of the early Bühler variety, heavily colonized with winter eggs of fruit tree red spider mite (*Metatetranychus ulmi*), were sprayed on February 25, 1959 with DNOC tar oil at the usual (2 %) and at an increased (3 %) concentration, and also with DNBP liquid (0.75 %). Later on in this test, the bud-burst spray FOLIDOL Oil (0.5 %) was also applied, on April 2. At this time, bud-burst was in full progress, and the blossom already began on April 4. On the day of spraying, it was observed that *Bryobia rubrioculus*\* was beginning to hatch out on the trees, which generally emerges only a few days ahead of the fruit tree red spider mite *Metatetranychus ulmi*. Therefore, the timing of the spray application of FOLIDOL Oil against the latter species was extremely good especially as the weather during the following days was so warm that the mass of winter eggs on the untreated trees had hatched within 12 days.

The test was evaluated as follows. Emerged larvae were collected daily in the laboratory from branches colonized by more than 200 winter eggs. Afterwards, branches were sampled outdoors, and a count was made of active stages on the leaf clusters, and full winter eggs still present on the wood. The results are given in Tables 1 and 2.

It was found that on the untreated checks, more than half the registered number of winter eggs were empty after 2 days, and about 75 % after 3 days. On the trees treated with DNOC tar oil, the peak of hatching was delayed by one day. But in the observation period, fruit tree red spider mite larvae nevertheless hatched out of almost half the winter eggs, whereby an increase of the spray concentration did not improve the effect, either. On the other hand,

\* Following the re-grouping of the former gooseberry red spider mite species *Bryobia praetiosa* into several species, the brown mite that colonizes plum trees is now referred to as *Bryobia rubrioculus*.



Table 1: Evaluation in the laboratory

| Spray and date of treatment    | No. of winter eggs April 4 | Percentage of hatching on |         |         |         |          |          | Total batching |
|--------------------------------|----------------------------|---------------------------|---------|---------|---------|----------|----------|----------------|
|                                |                            | April 6                   | April 7 | April 8 | April 9 | April 10 | April 14 |                |
| Untreated                      | 312                        | 54                        | 23      | 0.6     | 0.6     | 0.6      | 0.3      | 79.1           |
| DNOC tar oil 2%<br>February 25 | 354                        | 8                         | 26      | 6       | 2       | 4        | 0        | 46             |
| DNOC tar oil 3%<br>February 25 | 336                        | 6                         | 30      | 7       | 4       | 3        | 0        | 50             |
| DNBP 0.75%<br>February 25      | 318                        | 0                         | 0       | 0       | 0       | 0        | 0        | 0              |
| FOLIDOL Oil 0.5%<br>April 2    | 365                        | 0                         | 0       | 0.3     | 0.3     | 0        | 0        | 0.6            |
| Untreated                      | 234                        | 53                        | 21      | 3       | 0       | 0        | 0.4      | 77.4           |

Table 2: Evaluation in the field

| Spray            | Evaluation on April 14                                | Larv. in % | Evaluation on April 18                                | Larv. in % |
|------------------|-------------------------------------------------------|------------|-------------------------------------------------------|------------|
| Untreated        | 31 leaf clusters 2322 larvae on wood 174 winter eggs  | 93         | 22 leaf clusters 2105 larvae on wood 85 winter eggs   | 96         |
| DNOC tar oil 2%  | 28 leaf clusters 1510 larvae on wood 2134 winter eggs | 41         | 33 leaf clusters 2086 larvae on wood 1006 winter eggs | 68         |
| DNOC tar oil 3%  | 23 leaf clusters 1150 larvae on wood 1275 winter eggs | 47         | 26 leaf clusters 1292 larvae on wood 672 winter eggs  | 66         |
| DNBP 0.75%       | 38 leaf clusters 4 larvae on wood 5363 winter eggs    | 0          | 21 leaf clusters 287 larvae on wood 3546 winter eggs  | 7          |
| FOLIDOL Oil 0.5% | 49 leaf clusters 7 larvae on wood 2818 winter eggs    | 0          | 31 leaf clusters 24 larvae on wood 1491 winter eggs   | 2          |

no larvae were found on DNBП-treated trees, and only very few on those sprayed with FOLIDOL Oil.

The evaluation of samples collected outdoors, carried out on April 14, fully confirmed the results obtained in the laboratory. In the final count on April 18, it was found that hatching on the untreated trees was almost completed, on trees treated with DNOC tar oil mortality of winter eggs amounted at the most to 30 %, whereas mortality of over 90 % was obtained with DNBП and FOLIDOL Oil.

It is, however, expressly pointed out that the high rate of mortality registered for FOLIDOL Oil, as mentioned above, was obtained in especially favourable conditions. It remains to be established how the bud-burst spray acts in less favourable conditions — in other words, when hatching of red spider mite larvae out of winter eggs, due to cooler weather, does not begin until some time after the spray application, and also continues for a much longer period, as was the case in 1959.

